Changes in biodiversity patterns of soil Collembola caused by eucalyptus plantations in Portugal: a synthesis.

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RESUMO

Neste trabalho os autores fazem uma síntese da evolução do coberto vegetal em Portugal em relação com a sua situação geográfica e características climáticas, acentuando a distribuição e a área de ocupação, sobretudo nestas últimas décadas, das espécies de carvalhos, de pinheiros e do eucalipto. Esta exótica tem substituído gradualmente as espécies autóctones, representando, depois dos fogos florestais, o factor de perturbação mais negativo para os ecossistemas florestais. Os tipos de reflorestação estudados pelos autores em trabalhos já publicados são analisados, comparando comunidades de Colêmbolos existentes em plantações de eucalipto com as comunidades existentes nos povoamentos das espécies florestais autóctones mais representativas (*Pinus pinaster* Aiton, *Quercus ilex ballota* (Desf.) Samp., *Quercus suber* L., *Quercus pyrenaica* Willd. e *Quercus canariensis* Willd.). A análise global dos resultados, usando índices de diversidade e medidas de similaridade, mostraram que a substituição das espécies florestais autóctones pelo eucalipto causa efeitos marcantes nas comunidades de colêmbolos edáficos, com um decréscimo na abundância, número de taxa, diversidade e riqueza específica na maior parte dos casos. No entanto, os resultados não parecem indicar que seja o eucalipto, por si só, o responsável pela alteração do equilíbrio biocenótico destas comunidades. Outros factores que influenciem e induzam alterações ao nível da configuração do habitat, como as técnicas de maneio florestal empregues no estabelecimento e manutenção das plantações, devem ser tomados em conta. Considerando mais uma vez os efeitos negativos que uma acção de reflorestação pode ter na alteração dos padrões de diversidade da maioria dos grupos de artrópodes edáficos, com incidência especial nas espécies endémicas, torna-se necessário adoptar medidas urgentes com vista a conciliar a conservação da biodiversidade com as diversas acções de natureza silvícola.

ABSTRACT

In the present paper the authors make a review of the evolution of the vegetation cover in Portugal, in relation to its geographic location and climate, emphasising the distribution and the area of occupation, mainly through the last decades, of oak species, pine and eucalyptus. This exotic tree species has gradually replaced the native forests, representing the major disturbing factor for forest ecosystems, after forest fires. The types of reafforestation studied by the authors in papers already published are analysed, comparing Collembola communities from eucalyptus stands with the communities established in the most representative autochthonous forest species (*Pinus pinaster* Aiton, *Quercus ilex ballota* (Desf.) Samp., *Quercus suber* L., *Quercus pyrenaica* Willd. and *Quercus canariensis* Willd.). The overall data analysis, using both diversity indicators and similarity measures, has shown that shifting from the autochthonous species to eucalyptus caused strong effects on edaphic collembola communities, with a decrease in abundance, number of taxa, diversity and species richness in most cases. However, there is no clear indication that this exotic species may, by itself, be responsible for the disruption of the biocenotic equilibrium of these communities. Other factors that may induce changes in microhabitat configuration, like the management techniques used to install and run the plantations must be taken into account. Considering once more the negative effects that a reafforestation process may have on changing the diversity patterns of most soil arthropods, with special incidence on endemic species, it is necessary to adopt urgent measures in order to conciliate biodiversity conservation with forest activities.

INTRODUCTION

The particular geographic position of Portugal between the Eurosiberian and Mesomediterranean Regions has a strong influence on the country vegetation cover. Although most part of the Portuguese vegetation belongs to the Mediterranean Region, there is an Atlantic zone, belonging to the Eurosiberian Region, which comprehends nearly all the northern part of the country and also a line between the Ria de Aveiro and the Serra do Gerês. This Atlantic zone undergoes the influence of the warm Gulf stream with a relatively brief cold season and a temperate and dry Summer. The Mediterranean Region is characterised by mild and rainy Winters and long, hot and dry Summers. Therefore, the climate of Portugal presents Mediterranean characteristics with an Atlantic influence, mainly in the north.

Nevertheless, five million years ago, before the Quaternary glaciations, the south of Europe probably had a relatively warm and humid climate and a dense forest (Laurisilva) covered the north-western Mediterranean coasts. This designation is due to the fact that this vegetation type is composed of some tree species belonging to the *Lauraceae* family: *Laurus azorica* (Seub.) Franco, *Persea indica* (L.) Spreng., *Apollonias barbujana* (Cav.) Born. m., *Ocotea foetens* (Aiton) Baill. (Paiva, 1996).

Diniz (1984) (cited by Pais, 1989) refers a great landscape diversity in the Pliocene: *Ericaceae*, *Salix*, *Populus*, *Alnus*, arboreal associations as *Magnolia*, *Castanea*, *Myrica*, *Sequoia*, *Cathaya* and deciduous forests as *Quercus*, *Acer*, *Platanus*, *Tilia*, etc. In the mountains predominated *Pinus*, *Tsuga*, *Sequoia*, *Abies*, *Picea* and *Cupressaceae*.

The advance of ices, three million years ago, changed this climate and consequently its flora, leading to an impoverishment of our forests. In the Atlantic zone of Portugal a few species of the primitive forest, such as *Prunus lusitanica* L., *Rhododendron ponticum* L. ssp. *baeticum* (Boiss. and Reut.) Hand.-Mazz., *Ilex aquifolium* L., *Laurus nobilis* L., etc., are still present, some of them being found in the *Quercus* sp. or *Castanea sativa* Miller forests (Paiva, 1994).

Oak forests

In Portugal the last natural and native vegetation cover would probably be composed of an oak forest (Paiva, 1994). The decline of these forest ecosystems was mostly due to forest exploitation for the construction of boats during the discoveries period and to the agricultural and pastoral activities.

Nowadays the Portuguese flora comprehends eight species of genus *Quercus* all representatives of the ancient natural forest: *Q. robur* L. and *Q. pyrenaica* Willd. in the north-western and north-eastern regions respectively; *Q. suber* L. and *Q. ilex* L. ssp.*ballota* (Desf.) Samp. in the central and southern areas, the former in the western and the last in the eastern half of the territory, extending to the north. *Q. faginea* Lam. ssp. *faginea* is an Iberian endemic occurring in our country exclusively in Beiras and Trás-os-Montes provinces and *Q. faginea* Lam. ssp. *broteroi* (Cout.) Samp. extending from the province of Beira Litoral to the province of Algarve. *Q. canariensis* Willd. is restricted in our country to Serra de Monchique (Algarve province). *Q. lusitanica* Lam. and *Q. coccifera* L. are shrubby oaks existing in the centre and in the south of Portugal (Paiva, 1994).[1] At the present time *Q. suber* occupies an area of 713 000 ha, *Q. ilex ballota* an area of 462 000 ha and the other oak species only 131 000 ha (DGF, 2001).

Pine forests

A generalised opinion admits that the introduction of *Pinus pinaster* Aiton in Portugal was made in the XIII century by King D. Dinis with the aim to fix the littoral dunes. However, there are Portuguese and Spanish authors (Teixeira, 1944; Gil, 1991; Soares, 1994) who consider this species as autochthonous, due to the existence of Quaternary fossils, although they accept its expansion by human activities.

At the time of the discoveries the plantation of this forest tree species increased, because its wood was used in the manufacture of boats. This reafforestation begun with the "Lei das Árvores" (1565) and increased with the creation of the "Administração das Matas do Reino" (1824-1881), which gave rise to the "Serviços Florestais" (1886), currently "Estação Florestal Nacional" (Paiva, 1994).

In the XIX century there was in Portugal 210 000 ha of pine forest and in the XX century its plantation expanded, reaching 1 457 000 ha in 1978. In mid 90's the area of *Pinus pinaster* has fallen to 1 232 000 ha (Soares, 1994) and presently is reduced to 976 000 ha (DGF, 2001).

In our country there are two additional pine species: natural populations of *Pinus pinea* L. occupy the Mediterranean areas, corresponding to the sandy zones near the littoral. *Pinus sylvestris* L. existed formerly in the northern mountains, being represented nowadays by rare specimens (Paiva, 1994). A third species, *Pinus uncinata* Miller, which exists at present time in Pyrenees, Serra de Gudar and Soria (Spain), could also have been present in our country, because fossilized pine-cones of this species have been found in Serra do Gerês (H. Sainz Ollero - personal communication).

Eucalyptus plantations

Eucalyptus globulus Labill., native of Australia and Tasmania, was introduced in Portugal 150 years ago, exclusively for ornamental purposes (Alves, 1994). Only in 1926, it was used for the first time in the production of cellulose paste. In fact, in this year, the Swedish engineer C. D. Ekman has begun this production in a factory located in the river-side of Caima. It was the only factory that worked for over more than twenty five years (Caldas, 1991).

In the beginning of the 40's, when the "Companhia Portuguesa de Celulose" was founded, the eucalyptus occupied only 1,2 % of the 2,6 million of hectares of the forest area, with 30 000 ha of plantations (Soares, 1993). After the Second World War the government of the "Estado Novo" promoted the industrial development with special emphasis on the forestry industry and on the production of cellulose paste.

However, only a few years after the installation of the factory of Cacia, in the river-side of Vouga, in 1954, which

[1] Nevertheless, in Serra da Arrábida (Mata do Solitário) exist arboreous formations of *Q. coccifera* and *Q. faginea* ssp. *broteroi* (H. Sainz Ollero - personal communication).

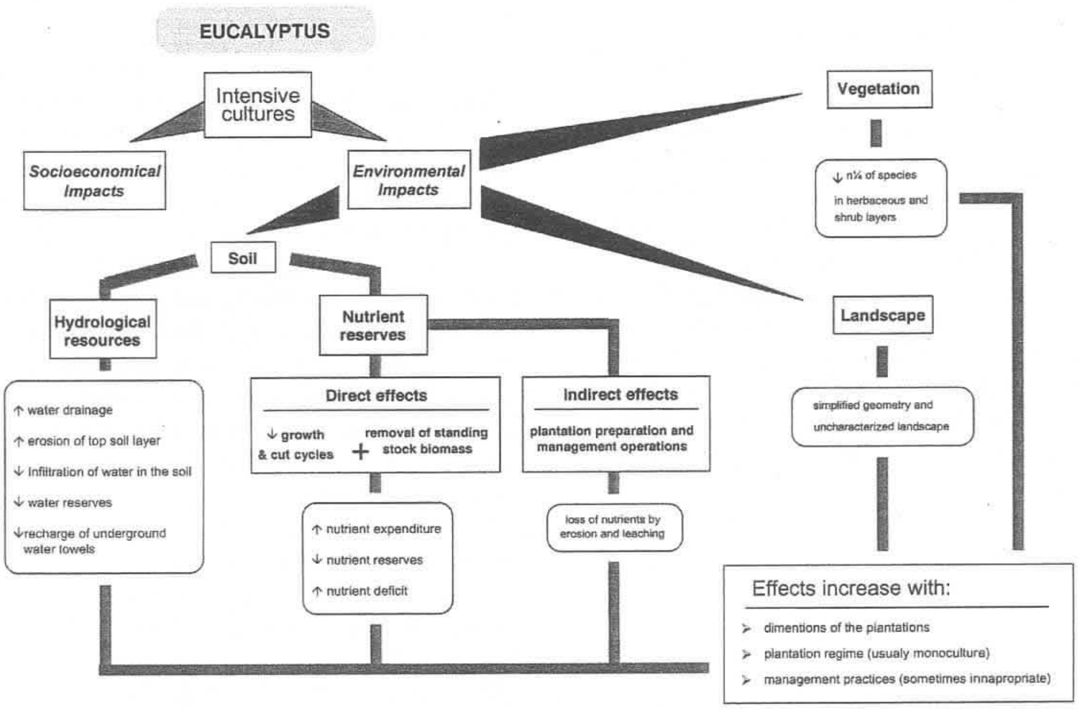


Figure 1 – Synoptical diagram on the impacts of the eucalyptus plantations.

used pine wood for the production of cellulose paste (Caldas, 1991), the eucalyptus begun to be employed on a large scale for this purpose. Therefore, it was only from the 60's on that eucalyptus plantations have expanded to reach an extension of 529 000 ha in the beginning of the 90's (Soares, 1993). In our days this area is mounted up to 672 000 ha (DGF, 2001). This expansion was carried out mainly by the cellulose industries (Celbi, Portucel, Soporcel and Caima) and, to a lesser extent, by private land-owners. The area occupied by eucalyptus plantations represents, at present time, 21 % of the forested area in the continental territory (3,2 million ha) being the dominating tree species after the pine tree and the cork-oak / holm-oak group.

The plantations of eucalyptus are located mainly in the western half of the territory (mainly in Beira Litoral), with one incursion to the interior, along the Tejo valley. In Beira Litoral region the districts of Coimbra and Aveiro present the highest values of occupation (30%). This fact may be due to the large incidence of forest fires, which often preceded the plantation of this exotic species. In the remaining areas of the territory the rate of occupation varies between 5% and 20% (Alves, 1994).

This massive plantation of eucalyptus in Portugal has been a subject of great controversy in recent years. The main advantages referred for this species exploitation are related mainly with its fast growth rate and the vegetative propagation. The eucalyptus tree grows much more rapidly than the pine tree and since new stems sprout from the remnants of the original trunk, which remains in the soil after the first cut, it allows rotations every 12 years without additional charges with soil preparation. Moreover, the light colour of its wood makes it suitable for the production of cellulose paste, therefore reducing the costs related with the whitening process.

The disadvantages arising from this activity are related mainly to environmental aspects. Two factors may contribute to the extent of the environmental impacts: (1) the dimensions of the plantation and (2) the type of occupation and management techniques used to run the plantation. With respect to the first point, the great extent of the planted areas, specially in the northern and central regions of the country, leads to an intensification of the impacts at local and regional level. Regarding the second aspect, the plantation of eucalyptus tree in a monoculture regime, connected to the preparation of the soil and management plans, are the factors responsible for the great extent of the ecological impacts. In Portugal more than 50% of the eucalyptus plantations are monocultures, thus having particular attributes in terms of structure and functioning of the biogeochemical cycles, different from native forests (Catarino, 1994; Deharveng, 1994).

These environmental impacts (summarised in Fig. 1), although inter-related to the intrinsic complexity of a forest system, may be separated into different vectors: soil (including effects on the hydrological resources and nutrient reserves), landscape (vegetation structure) and fauna. These effects arise mainly from the fact that the eucalyptus is a high water consuming species; it reduces soil fertility since its leaves decompose very slowly leading to a decrease in organic matter and nutrients in the soil. The lack of organic matter also results from poor shrub and herbaceous layers due to a low availability of water and to a scarcity of light caused by the blocking of sunlight by the treetops of the fast growing eucalyptus. This absence of shrub and herbaceous layers, connected to the low water infiltration into the soil, leads to an increase of water movement on soil surface, promoting soil erosion.

In most cases, after 3 rotations (approximately 36 years), if the remnants of the cut trunks remain in the land, a rapid colonisation by "root rot" fungi (*Armillaria* sp. and *Rosellinea necatrix*) occurs. In an early stage these fungi develop as saprobiotic organisms, but, when a new agricultural or forestry plantation is established, they attack the root system of the young plants, often reducing dramatically the viability of the following crops.

In conclusion, the extensive plantation of this allochthonous species in our country is leading, in most cases, to a large disruption of soil living communities and to a nutrient depletion of forest soils. It is considered the second most important ecological disturbance on Portuguese forests after forest fires (Sousa *et al.,* 1997).

Figure 2 – Geographic location of the studied sites.

MATERIALS AND METHODS

Types of reafforestation analysed

In Portugal different types of reafforestation with *E. globulus* have been studied in recent years. Here we intend to summarize the most important characteristics of the studied stations, especially in terms of vegetation cover and habitat configuration, since we believe that these attributes constitute key factors in the interpretation of the results.

The available published studies are mainly focused in analysing the effects of reafforestation with eucalyptus, comparing Collembola communities from this exotic with the communities established in the most representative autochthonous forest species. The studied types are: 1) *P. pinaster* versus *E. globulus* (Figueiredo *et al.,* 1985; Vasconcelos *et al.,* 1994; Ferreira *et al.,* 1994; Gama *et al.,* 1994, 1995); 2) *Q. ilex ballota* versus *E. globulus* (Gama *et al.,* 1994a; Sousa & Gama, 1994; Sousa *et al.,* 1997); 3) *Q. suber* versus *E. globulus* (Gama *et al.,* 1989, 1991; Sousa *et al.,* 1997); 4) *Q. canariensis* and *Q. suber* versus *E. globulus* (Barrocas *et al.,* 1998) and 5) *Q. pyrenaica* versus *E. globulus* (Sousa *et al.*, in press) (Fig. 2):

1) Study areas of the first pair of stations (*P. pinaster* vs. eucalyptus) were located in: (a) Serra da Lousã, 20 Km East of Coimbra at 550-600 m in altitude; (b) Sever do Vouga, district of Aveiro at an average altitude of 300 m and (c) Cercal (Caldas da Raínha) district of Leiria.

At Serra da Lousã, pine wood stands, aged about 48 years, had shrub and herbaceous layers composed of *Calluna vulgaris* (L.) Hull., *Lithodora prostrata* (Loisel.) Griseb, *Andryala integrifolia* L. and *Polygala microphyla* L. In eucalyptus plantations, aged about 28 years, at the end of the second rotation, the shrub layer was very poor, having only some specimens of *C. vulgaris* and *Ulex europaeus* L. (Gama *et al.,* 1994; Vasconcelos *et al.,* 1994).

At Sever do Vouga, stands of *P. pinaster* and *E. globulus* (in second rotation) were contiguous. On both sites trees, aged of 15 years, were planted in 1977, four years after a forest fire; before this fire the entire area was covered with pine wood. On both sites trees were planted in grooves following the altitude lines, which led to an accumulation of leaf litter. Herbaceous and shrub layers of both stands were composed mainly of *Pteridium aquilinum* (L.) Kuhn, *U. europaeus*, *Erica* sp., *C. vulgaris* and *Chamaespartium tridentatum* (L.) Gibbs (Ferreira *et al.,* 1994; Gama *et al.,* 1995).

Stands of *P. pinaster* from Cercal (designated Cercal 1) were aged about 25 years and presented an abundant shrub layer. Concerning eucalyptus plantations, three parcels, aged of 5, 15 and 25 years, have been studied; all presented a very poor shrub layer. These plantations were exploited with clear cuttings every 10 years (Figueiredo *et al.,* 1985; Cabral & Martins, 1985).

2) Study areas of the second pair of stations (*Q. ilex ballota* vs. eucalyptus) were located near Idanha-a-Nova, in the surroundings of Marechal Carmona Dam, district of Castelo Branco, at an average altitude of 300 m. Oaks appeared both as mature trees, aged more than 30 years, and young plants, contributing to the dense thickness of the shrub layer. This was dominated by *Cistus ladanifer* L., *C. salvifolius* L. and *Lavandula stoechas* L. The soil of eucalyptus stand presented intense signs of management, with a scarce vegetation cover. Trees, aged about 10 years, were planted in grooves opened along the altitude lines, in which there was some accumulation of eucalyptus leaves and bark (Gama *et al.,* 1994a; Sousa & Gama 1994; Sousa *et al.,* 1997).

3) Study areas of the third pair of stations (*Q. suber* vs. eucalyptus) were situated in Quinta de Santo António - Cercal (Caldas da Raínha), district of Leiria, and in Almeirim, district of Santarém.

Cork-oak biotope in Quinta de Santo António (designated Cercal 2) presented a shrub layer composed of *Arbutus unedo* L., *Ulex minor* Roth, *Erica* sp., *Cistus* sp., *Rubus* sp., *Hedera helix* L., *Lonicera etrusca* Santi, *Myrtus communis* L., *C. tridentatum* and *P. aquilinum.* In eucalyptus site, where the trees were aged about 11 years, at the end of the second rotation, neither shrub layer nor herbaceous layer were present (Gama *et al.,* 1989, 1991; Serralheiro & Madeira, 1990).

In the cork-oak stand from Almeirim, the specimens of *Q. suber*, aged about 30 years, were distributed in a non regular way and the vegetation cover was quite heterogeneous, composed mainly of *C. tridentatum*, *C. salvifolius*, *C. vulgaris*, *L. stoechas* and *L. prostrata*. In some points of the soil surface there was an accumulation of leaves and branches of cork - oak. In the eucalyptus stand, the vegetation cover was very dense with trees, aged about 22 years, in second rotation, also distributed in a non regular way. The fact that this stand was not exploited for commercial purposes, with disturbances being limited to clear cutting times, every 10-12 years, led to the development of an abundant shrub cover, with the same dominant species found in the *Q. suber* stand. In addition, there was an accumulation of eucalyptus leaves, branches and bark on the soil surface (Sousa *et al.*, 1997).

4) Study areas of the fourth pair of stations (*Q. canariensis* and *Q. suber vs.* eucalyptus) were located in Serra de Monchique, Algarve, at 500 - 600 m of altitude.

In the stands of *Q. canariensis* biotope, shrub and herbaceous layers, dominated by *P. aquilinum*, *Viburnum tinus* L., *Cytisus scoparius* (L.) Link, *C. salvifolius* and *Erica arborea* L., were associated to the presence of oak trees. This oak species presents a very restricted occurrence both in Portugal and Spain, with Serra de Monchique being its exclusive area in Portugal. This tree species appears nowadays only in small and scattered clumps (Afonso, 1991) or as individual specimens.

With respect to *Q. suber* biotope, two different sites have been analysed, which can be distinguished by their vegetation cover. In the first site the herbaceous and shrub layers were composed of *C. salvifolius*, *E. arborea* and *Viburnum tinus* L.. The second site presented a very scarce vegetation cover composed mainly by Gramineae. In terms of analysis, these two sites were pooled.

In eucalyptus plantations where the trees were in second rotation, three different sites have been sampled. The first site presented an abundant vegetation cover constituted by *Daphne gnidium* L., *A. unedo*, *C. salvifolius*, *C. ladanifer*, *C. vulgaris* , *Erica lusitanica* Rudolphi and *L. stoechas*. In the second site there was only an herbaceous layer composed mainly of *P. aquilinum* and a great accumulation of eucalyptus leaves and bark on the soil surface.The third site had also a large accumulation of eucalyptus leaves and bark and the vegetation cover was dominated by *P. aquilinum*, *E. arborea*, *C. scoparius*, *C. salvifolius*, *A. unedo*, *V. tinus* and *Rubus* sp. (Barrocas *et al.*, 1998).

5) The study area of the fifth pair of stations (*Q. pyrenaica* vs. eucalyptus) was located in Fafe, district of Braga. The type of landscape is known as "Terras Altas" and it is mainly composed of patches of oak forest (*Q. pyrenaica* and *Q. robur*) mixed with small agricultural parcels and pasture areas.

The oak forest was characterized by a dense vegetation cover. It was possible to find oaks in different growth stages ranging from young oaks, contributing to a dense shrub layer, to very high oak trees. In some sectors of the stand the trees were not allowed to grow completely since, from time to time, their branches were cut for charcoal production. The herbaceous layer was very diverse but dominated by *Briza maxima* L., *Avena sterilis* L., *Hordeum murinum* L., *Asphodelus lusitanicus* P. Cout., *Scilla hispanica* Miller, *Arenaria montana* L., *E. arborea* and *L. stoechas*. The shrub layer, besides the presence of young oaks, was composed mainly by *C. tridentatum* and *Retana monosperma* L.. The soil was characterized by a well defined organic profile, with a thick litter layer. The eucalyptus stand was characterized by mature trees in second rotation. The plantation showed no signs of ordinary commercial exploitation, without regular cleanings or tree cuting for the last 12 or 15 years. The shrub layer was almost inexistent and the herbaceous layer was heavily impoverished being dominated by *P. aquilinum* and Gramineae (Sousa *et al.*, in press).

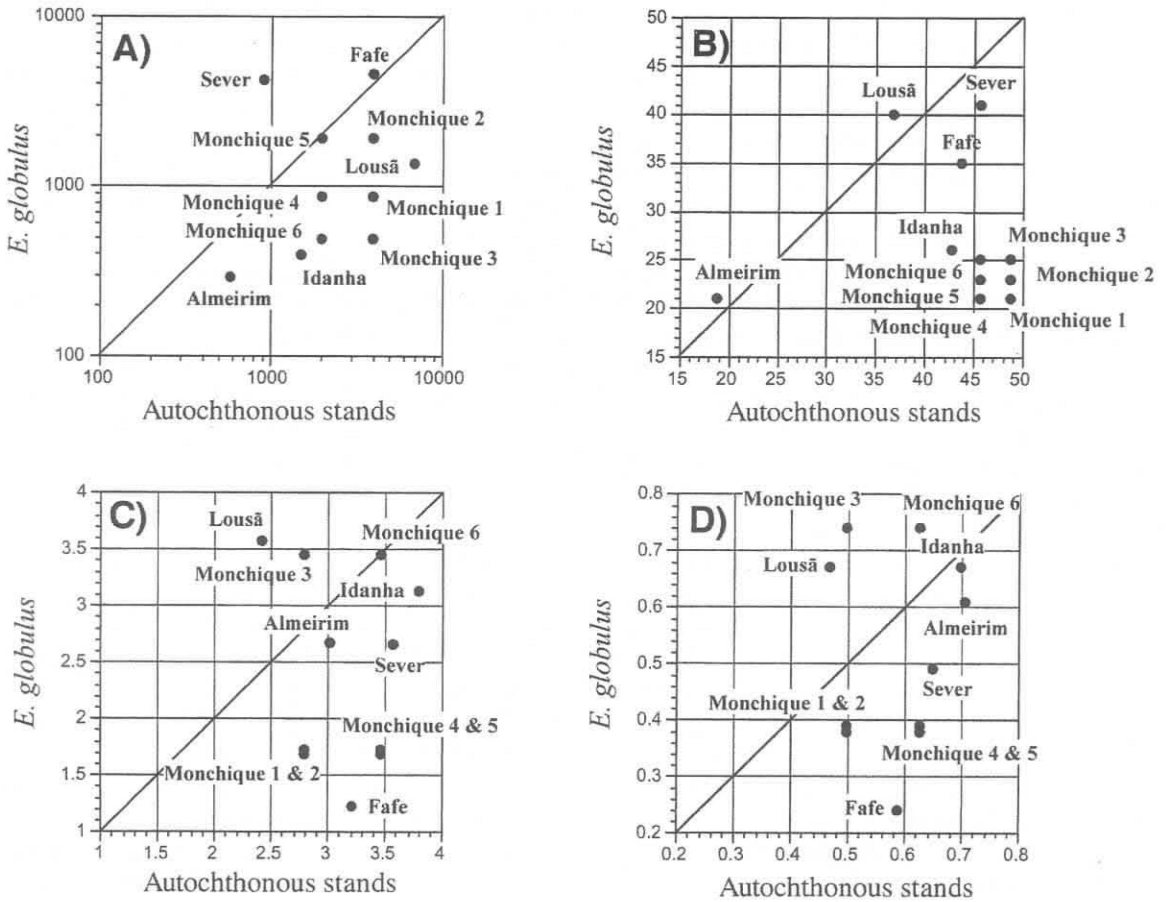
Data analysis

A general analysis of the published results is done here. We adopted the scheme used above, analysing each type of reafforestation separately. Without the aim of doing an extensive analysis for each case, we have concentrated our efforts on analysing two types of parameters that could give a clear indication of the possible effects caused by the change from an autochthonous tree species to eucalyptus: (1) biodiversity indicators: abundance, number of taxa, species diversity (Shannon), evenness (Pielou) and species richness (Margalef); (2) analysis of similarity, comparing average similarity values in the autochthonous stand (called control groups) with the average similarity values of the autochthonous stands vs. the eucalyptus stands (called treatment groups). This method allows to verify statistically any possible differences in the fauna spectrum of both communities assuming that, if they resembled, no significant differences could be observed on the above comparisons (Sousa & Gama, 1994; Sousa *et al.*, 2000). In the majority of the cases analysed, the values of these parameters are already given by the correspondent authors; in other cases they were calculated by us based on the raw data given by the authors.

RESULTS

At the studied sites mentioned above, the shift from the autochthonous tree species to the eucalyptus led to different responses in the biodiversity indicators. Figure 3 represents a synthetic overview of the changes on those indicators measured in native versus eucalyptus stands. The values presented refer to the total soil profile, not distinguishing organic and mineral horizons nor epigeic fauna.

Starting with *P. pinaster* vs. eucalyptus stations, we can notice that at Lousã site native Collembola populations supported the highest abundance of both sites, being represented by 7131 specimens, while eucalyptus plantation had only 1362 individuals (Fig. 3A). In terms of number of taxa (Fig. 3B), in the exotic stand 40 taxa have been identified against 37 in the original stand (Gama *et al.*, 1994; Vasconcelos *et al.*, 1994). In opposition, at Sever do Vouga station, the abundance was higher in eucalyptus (4197 individuals) but the number of taxa (41) was lower



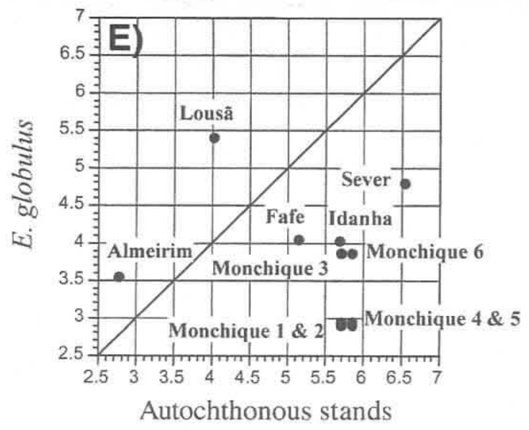


Figure 3 – Characterization of biodiversity indicators for some pairs of studied stations: A) Abundance; B) Number of taxa; C) Species diversity values (Shannon); D) Evenness (Pielou) and E) Species richness (Margalef). Diagonal isolines indicate equivalent values for the autochthonous species and eucalyptus. **Lousã** – *P. pinaster* vs. *E. globulus*; **Sever** – *P. pinaster* vs. *E. globulus*; **Idanha** – *Q. ilex* vs. *E. globulus*; **Almeirim** – *Q. suber* vs. *E. globulus*; **Monchique** (1-3) – *Q. suber* vs. *E. globulus* (1-3); **Monchique** (4-6) – *Q. canariensis* vs. *E. globulus* (4-6); **Fafe** – *Q. pyrenaica* vs. *E. globulus*.

than in the autochthonous site, which presented 935 specimens and 46 taxa (Gama *et al.*, 1995).

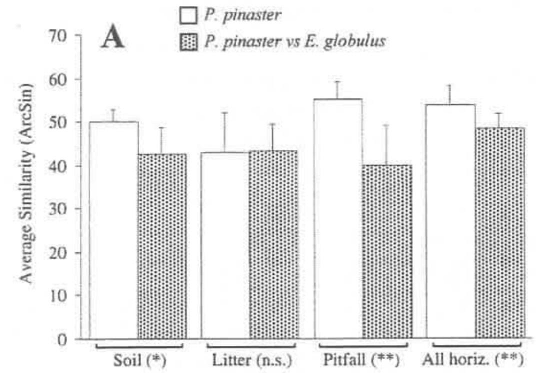
In Cercal 1 station, not represented in figure since it comprehends several sampling periods, Figueiredo *et al.* (1985) found a reduction on the total number of individuals and species in the mesofauna of eucalyptus in relation to the coppices of pinewood during an entire year of study.

In respect to diversity, evenness and species richness (Fig. 3 C, D and E), all these parameters were lower under the native forest in Lousã, while in Sever do Vouga, the largest values were found at the pine stand. In the case of the first site, this bias towards the eucalyptus, especially in species diversity values, may be attributed mainly to changes in evenness and not to the different number of taxa identified (Vasconcelos *et al.*, 1994). These authors, when analysing each horizon separately, found that differences between stands were also related to differences in evenness. In relation to species richness, differences observed were related mainly to the number of individuals present.

At Sever do Vouga site, the same reasons could be applied to explain the differences observed on these parameters, this time in favour of the native tree species. Gama *et al.* (1995), when analysing each horizon individually, found that differences in species diversity and species richness could be attributed to evenness values and abundances respectively, since equivalent horizons at the two stands presented a similar number of taxa.

Comparing the faunal spectrum of the native and exotic tree species at each site, by means of a similarity analysis, we

can denote that at Lousã site the similarity values of the treatment groups (autochthonous stand vs. eucalyptus) are significantly different from the values on the control groups (autochthonous stand) in all levels analysed, except for the organic horizon (Fig. 4A). In the case of Sever do Vouga site, the treatment values were different from the control values only when the epigeic fauna was considered separately or when all the strata were analysed together (Fig. 4B).



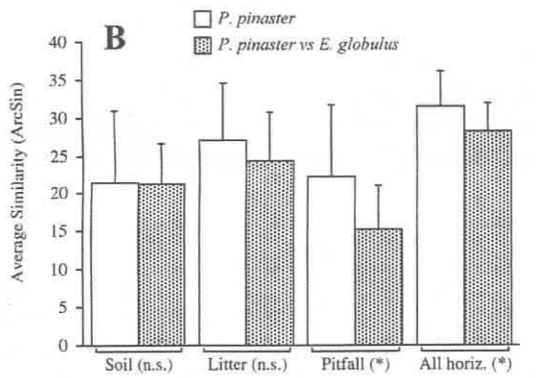


Figure 4 – Average similarities (+SD) on control (pinewood stands) and treatment (pinewood vs. eucalyptus) groups for Lousã (A) and Sever do Vouga (B) sites. Groups were compared by a t-test: n.s. non significant; * $p<0.05$; ** $p<0.01$.

The overall analysis of this data showed that although there was a change in Collembola biodiversity patterns caused by shifting from pine to eucalyptus, the signs of rupture were not so evident; in fact the change seemed to be slightly favourable for the eucalyptus in the case of Lousã site. As discussed later, this weak separation should be attributed mainly to the resemblances in habitat configuration between both stands at each site.

At the *Q. ilex ballota* vs. eucalyptus stations, at Idanha site, holm-oak had the richest and most abundant Collembolan populations of both stands, represented by 1562 specimens and 43 taxa (Fig. 3 A and B). In contrast, eucalyptus had only 396 specimens and 26 taxa (Gama *et al.,* 1994a; Sousa and Gama 1994). This separation can be confirmed by the values of species diversity, evenness and species richness, which were significantly higher in the native forest than in the exotic stand (Fig. 3 C, D and E).

These clear signs of rupture of the community structure caused by the shift from one tree species to the other can also be observed in the similarity analysis (Fig. 5); with the exception of the mineral horizon, where the high variability of the values led to non significant differences, all levels analysed show a visible and significant decrease in the similarity values of the treatment groups in relation to the control groups. The impoverishment of the eucalyptus fauna was mainly caused by the reduction or even disappearance of particular species from the Isotomidae and Hypogastruridae groups; these species are considered typical forest species and they are very demanding in terms of habitat configuration and unable to cope with the new habitat conditions existing in the eucalyptus stand.

From all the reafforestation cases analysed, this is one of

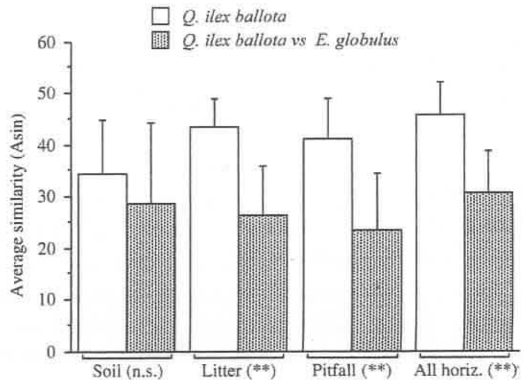


Figure 5 – Average similarities (+SD) on control (holm oak stand) and treatment (holm oak vs. eucalyptus) groups for Idanha site. Groups were compared by a t-test: n.s. non significant; ** $p<0.01$.

the most representative in terms of the strong influence that forest management practices can have at the level of the soil arthropod fauna. The frequent disturbances in the system, by regular cleaning and removal of the accumulated standing stock biomass, caused a drastic change in the habitat structure of the plantations.

Continuing with the first set of *Q. suber vs.* eucalyptus stations (Almeirim and Cercal 2 sites) we can notice that at Almeirim, the substitution of the cork-oaks by eucalyptus trees caused only a minor disruption of the Collembola community in comparison to the case mentioned above. Sousa *et al.* (1997) found a sligth reduction in the number of Collembola species (19 *vs.* 21) and in species richness values in the native forest while the observed values of abundance (604 *vs.* 291), diversity and evenness were lower in the exotic stand (Fig. 3 A-E). These differences were more evident when considering all strata together, since if the two horizons are consider separately, the values of these parameters are approximately the same. Despite the small magnitude of the differences found, the analysis of similarity revealed significant differences among control and treatment groups in the majority of the levels analysed (Fig. 6).

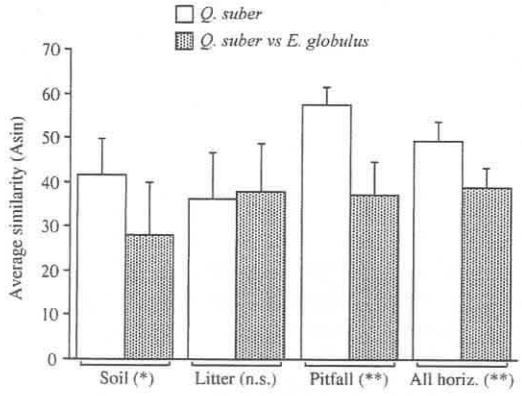


Figure 6 – Average similarities (+SD) on control (cork oak stand) and treatment (cork oak vs. eucalyptus) groups for Almeirim site. Groups were compared by a t-test: n.s. non significant; * p<0.05; ** p<0.01.

At Quinta de Santo António (Cercal 2 site), where the authors collected several samples for more than 1 year, a clear separation between the two stands could be observed at every level of analysis (Gama *et al.,* 1991). Biodiversity indicators, calculated on base of raw data presented, show a strong bias towards the cork-oak stand in every sampled period considered (Fig. 7); it is notorious the richness of the cork-oak stand in quantitative and qualitative terms and also the strong impoverishment of the mineral horizon of the exotic stand. Gama *et al.* (1991) also presented data based on a correspondence analysis (not represented here), applied to the Collembolan populations occurring on both stands, that reveals a clear separation between the two types of biotopes and between the organic and mineral horizons of each biotope.

The discrepancy in the responses obtained at the two sites, Almeirim and Cercal 2, is, once more, a clear sign of the key role that habitat configuration plays in the interpretation of the results. Although being represented by quite impoverished faunas, both stands at Almeirim site presented a similar structure on the organic horizon and vegetation cover; in opposition, cork-oak and eucalyptus stands at Cercal 2 site presented a quite different structure, with the exotic stand being almost deprived from herbaceous and shrub layers.

At Serra Monchique we considered one pooled *Q. suber* site versus three eucalyptus plantations (Monchique 1-3) and one *Q. canariensis* site versus the same three eucalyptus stands (Monchique 4-6). In general terms there was no significant difference in the average abundance among the studied biotopes, although the total abundance was higher in the oak biotopes (Fig. 3A). Considering the mean and total numbers of taxa, oak biotopes have both higher values than eucalyptus sites (Fig. 3B); this was especially evident in the organic horizon (Barrocas *et al.,* 1998).

This separation is confirmed by the species diversity and richness values which are higher in oak biotopes, especially in *Q. canariensis*, than in eucalyptus. The species diversity values in the comparison with Eucalyptus III (Monchique 3 and 6) seem to misfit the general pattern, e.g. lower diversity for the allochthonous biotopes. The reason for this is related to the increase in evenness (when compared to the other eucalyptus sites) and not to a difference in species number. The lower values of evenness on the other sites result from the great abundance of some particular species, especially *Folsomia candida* (in *Q. canariensis*), *Folsomia sexoculata* (in *Q. suber*, Eucalyptus I and Eucalyptus II) and *Xenylla brevisimilis mediterranea* (in Eucalyptus I and Eucalyptus II) (Gama *et al.,* 1997; Barrocas *et al.,* 1998).

The separation between autochthonous and exotic sites is verified by the similarity analysis. Significant differences can be observed in almost all levels analysed in the six cases considered (Figs. 8 and 9). According to Barrocas *et al.* (1998) the effects of the introduction of eucalyptus seemed to be more pronounced at the *Q. suber* site than at the *Q. canariensis* site. The disruptions of the autochthonous communities were caused mainly by low representativity or disappearance of some epigeic species at the eucalyptus sites and by a shift in the dominance structure of those communities.

Finally at the *Q. pyrenaica* vs. eucalyptus stations (site located at Fafe) the shift from the autochthonous tree species towards eucalyptus caused also a clear disruption in the Collembola community. Despite the higher number of individuals identified at the eucalyptus station (4569 individuals in relation to the 4117 specimens in the oak station), all the other biodiversity indicators were clearly biased towards the autochthonous species (Fig. 3 A-E).

Analysing organic and mineral horizons separately (data not presented here), the greatest differences were observed on the organic horizon, with the disappearance and reduction of several species from the Hypogastruridae, Onychiuridae and Isotomidae groups at the eucalyptus station. It was also observed a shift in the dominant species, with *Tetracanthella proxima* having a very high abundance in the exotic tree species plantation (this was also the main cause for the strong differences in terms of species diversity values between the two stations, especially in the mineral horizon). These changes in Collembola community are also quite clear in the similarity analysis data; a strong and significant decrease can be observed in all levels considered (Fig. 10). The strong differences in habitat configuration and vegetation cover (decrease in litter layer thickness and reduction in herbaceous and shrub cover) are, once more, at the centre of these differences between Collembola communities from both stands.

DISCUSSION

In recent years plantations of exotic tree species have been increasingly developed at the expense of the remaining native forests, to the point where many European countries have lost most of their semi-natural forests.

In Portugal, native *Pinus* spp. and *Quercus* spp. forests have been replaced by *Eucalyptus* plantations over thousands of hectares and, as seen before, with drastic effects on edaphic Collembola communities (Gama *et al.,* 1989, 1991, 1994, 1994a, 1995; Sousa & Gama, 1994; Vasconcelos *et al.,* 1994). Reafforestation by exotic conifers in natural oak forests of Navarra (Northern Spain) has caused a clear rupture of the ecological equilibrium of soil fauna (Arbea & Jordana, 1985; Jordana *et al.,* 1987).

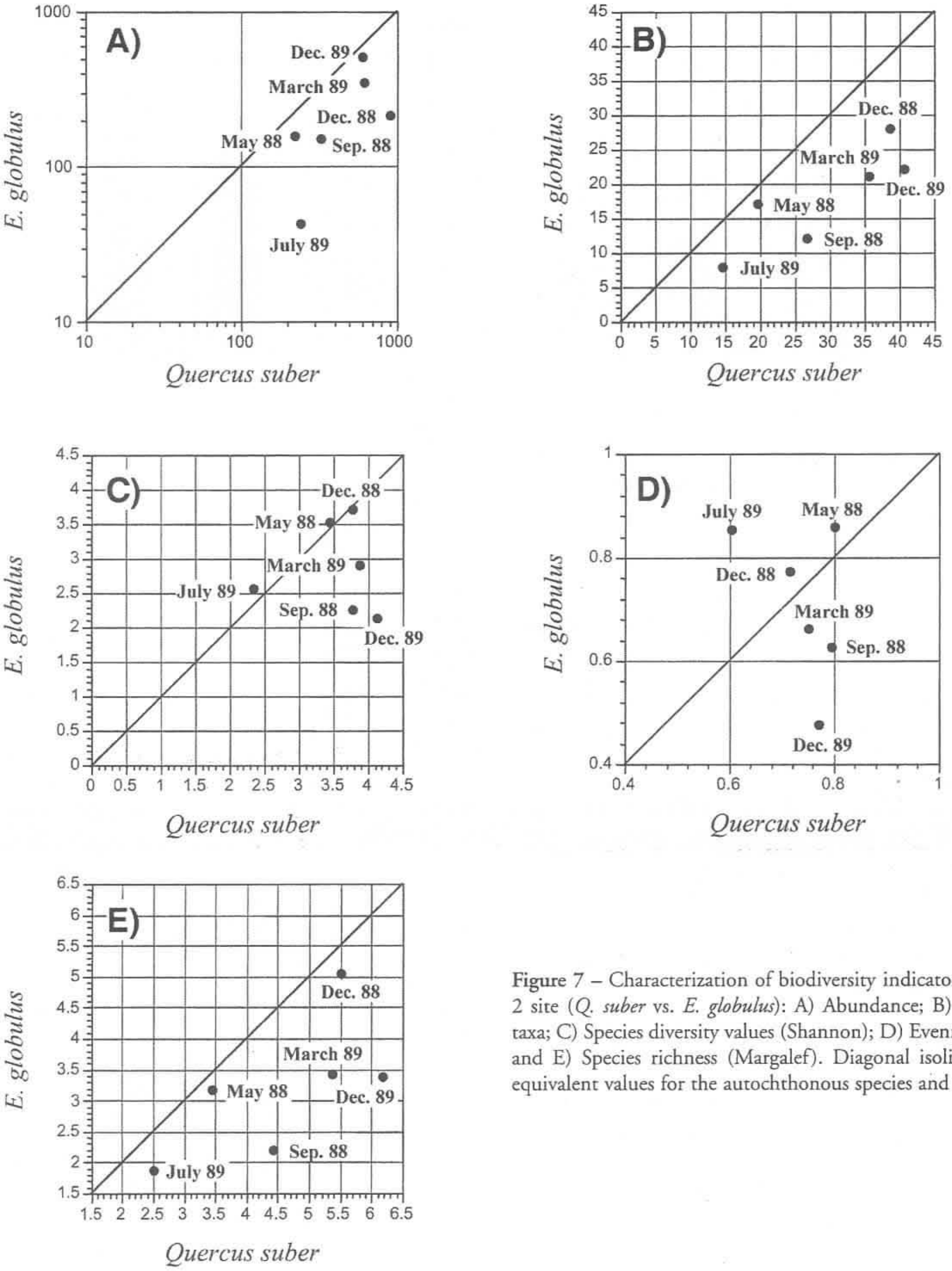


Figure 7 – Characterization of biodiversity indicators for Cercal 2 site (*Q. suber* vs. *E. globulus*): A) Abundance; B) Number of taxa; C) Species diversity values (Shannon); D) Evenness (Pielou) and E) Species richness (Margalef). Diagonal isolines indicate equivalent values for the autochthonous species and eucalyptus.

In Central Pyrenees (France) Collembolan communities from semi-natural beech forests were compared to equivalent communities from conifer plantations. Species diversity was impoverished in these plantations, particularly the endemic component, which was highly vulnerable to reafforestation suffering a severe decrease in abundance and species richness (Deharveng, 1996). These findings are of prime concern for conservation, and although data are lacking for several other Arthropod groups, it is likely that this type of reafforestation may have strong negative effects on the diversity of most edaphic Arthropod groups, with special incidence on endemic species (Deharveng, 1996).

In the presence of these facts we are obliged to answer how to preserve biodiversity in face of reafforestation disturbance. To conciliate biodiversity conservation and reafforestation, a few basic principles must be established at local, regional, national and European level, most of them developing compromises between protection and production forests (Dehaveng, 1994).

In England, for instance, there is now considerable public support for the establishment of new forests in the interests of nature conservation, but also for commercial timber production (Watkins, 1993). Nevertheless, this author advises that it is very important to avoid establishing these new forests on existing semi-natural habitats, especially when other already disturbed areas exist.

At an European level, Southern forests, from Portugal to Greece, are the only ones which host a significant number of endemic biota, representing the most precious

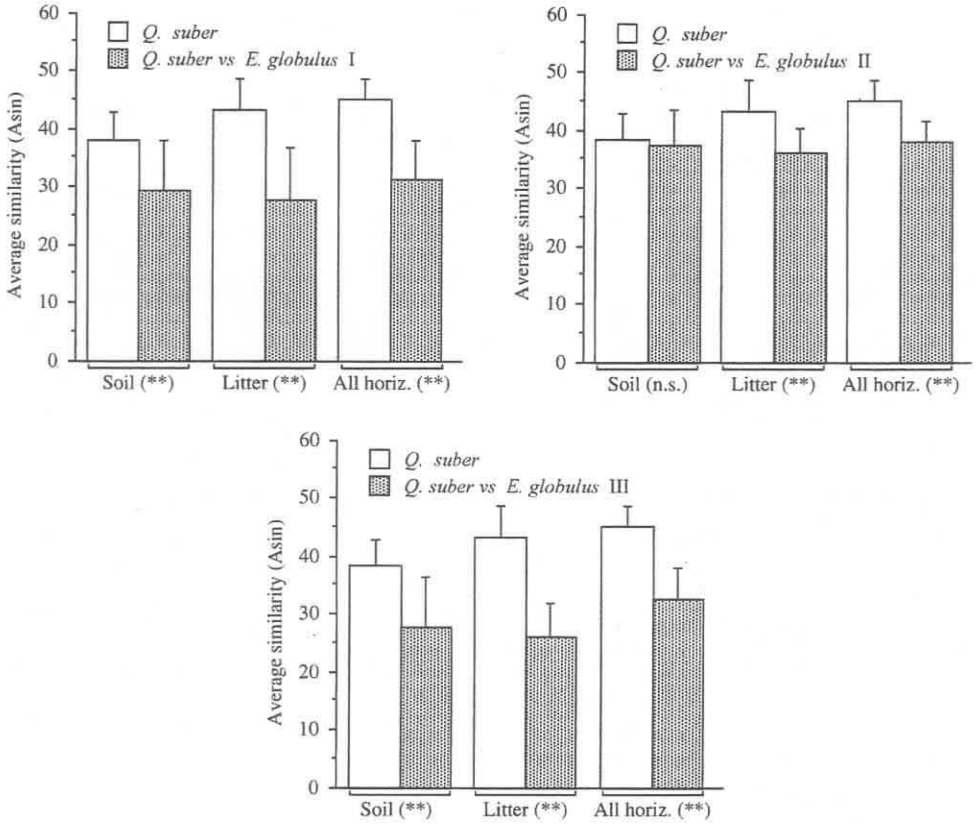


Figure 8 – Average similarities (+SD) on control (cork oak stand) and treatment (cork oak vs. eucalyptus) groups for Monchique site (Monchique 1–3). Groups were compared by a t-test: n.s. non significant; ** p<0.01.

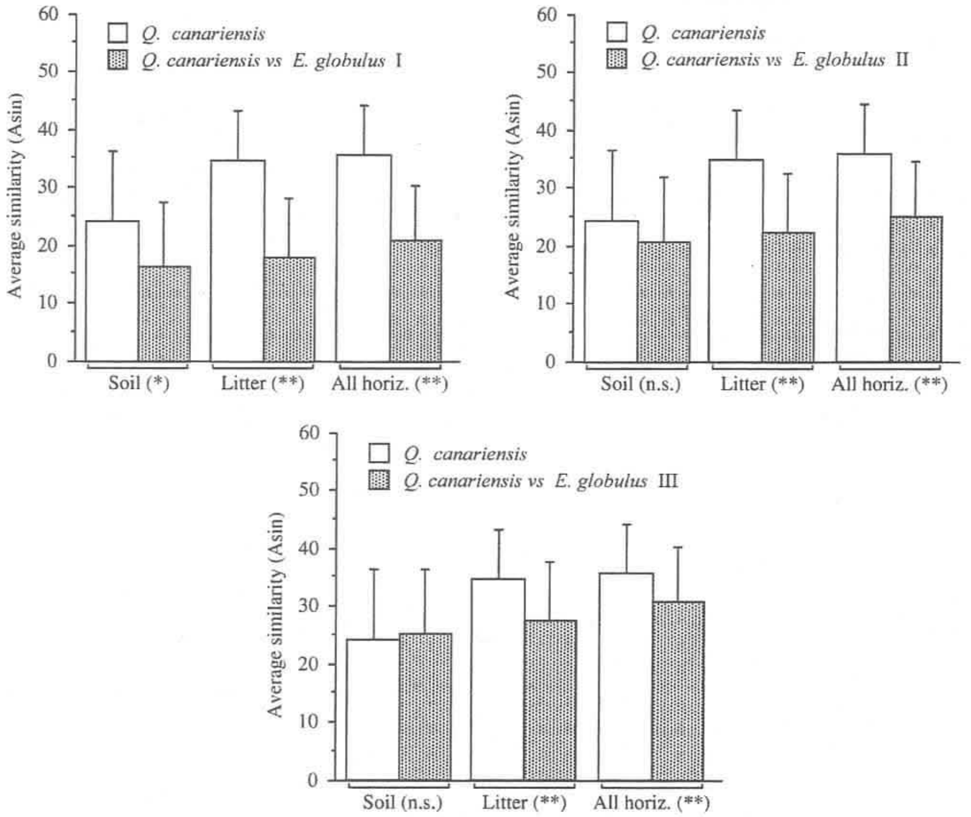


Figure 9 – Average similarities (+SD) on control (canary oak stand) and treatment (canary oak vs. eucalyptus) groups for Monchique site (Monchique 4–6). Groups were compared by a t-test: n.s. non significant; ** p<0.01.

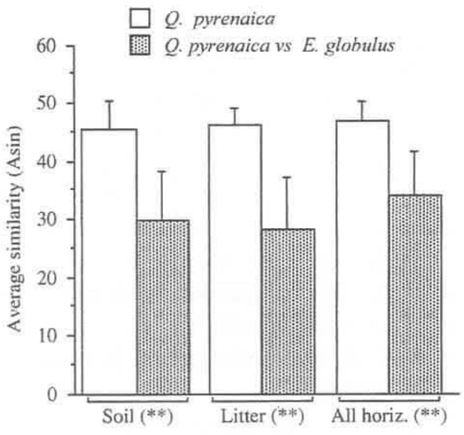


Figure 10 – Average similarities (+SD) on control (black oak stand) and treatment (black oak vs. eucalyptus) groups for Fafe site. Groups were compared by a t-test: n.s. non significant; ** $p<0.01$.

component of global diversity. Conserving these areas should be considered, in this way, a priority. In some areas of Portugal, where eucalyptus plantations constitute the sole ecosystem on extensive surfaces, habitats which may have retained some of the native species of value for biodiversity should be carefully preserved (Deharveng, 1994). The major threat to biological diversity is the loss of habitat and the most important means of protecting biological diversity is preserving habitat (Primack, 1998).

There is no clear indication that the exotic tree species may induce, by itself, a change in the biocenotic equilibrium of soil communities. Other factors, concerning forestry practices must be considered. In Portugal, as seen before, plantation of eucalyptus have been submitted to different installation and management procedures leading to different responses in terms of disturbance of Collembola communities. The practice of opening grooves allows an enrichment of the system due to a large accumulation of organic debris and to the development of a rich vegetation cover, creating suitable conditions for springtails. On the contrary, the regular cleaning of shrub and herbaceous vegetation and the removal of litter layer seem to induce a decrease of survival chances for these edaphic insects. Indeed the existence of a well formed organic horizon is essential to promote favourable microhabitat conditions for edaphic Collembola, mainly in terms of moisture and food supply (Gama *et al.*, 1995; Sousa & Gama, 1994). In fact, the degree of similarity between the fauna communities from native and exotic stands of the pinewood stations (Sever do Vouga and Lousã) and the difference between communities from holm-oak, cork-oak and black-oak stations (Idanha, Almeirim, Cercal 2 and Fafe) can be attributed more to microhabitat configuration than to the different tree species themselves.

The overall results found help to highlight the importance of the installation and management procedures in eucalyptus plantations in explaining their effects on the Collembola communities. Any artificial reafforestation constitutes one of the most extensive disturbances on natural and semi-natural edaphic ecosystems. Nevertheless the magnitude of these disturbances is conditioned by the new soil conditions related not only with the characteristics of the exotic tree, but also with the adopted management practices (Sousa *et al.*, 2000).

Therefore, face to the complexity of the reafforestation problem, the next step should consider not only mensurative experiments, but associate experimental and manipulative field studies. These should analyse the impact of specific forest management techniques (with exotic and autochthonous species) embracing not only structural biodiversity aspects, but also looking at effects on a functional level (soil biological process such as decomposition and nutrient cycling). Only this way, we can obtain solid information about this problem and develop more realistic management rules for forests.

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